What can Long-Term Experiments teach us about Potassium Management?

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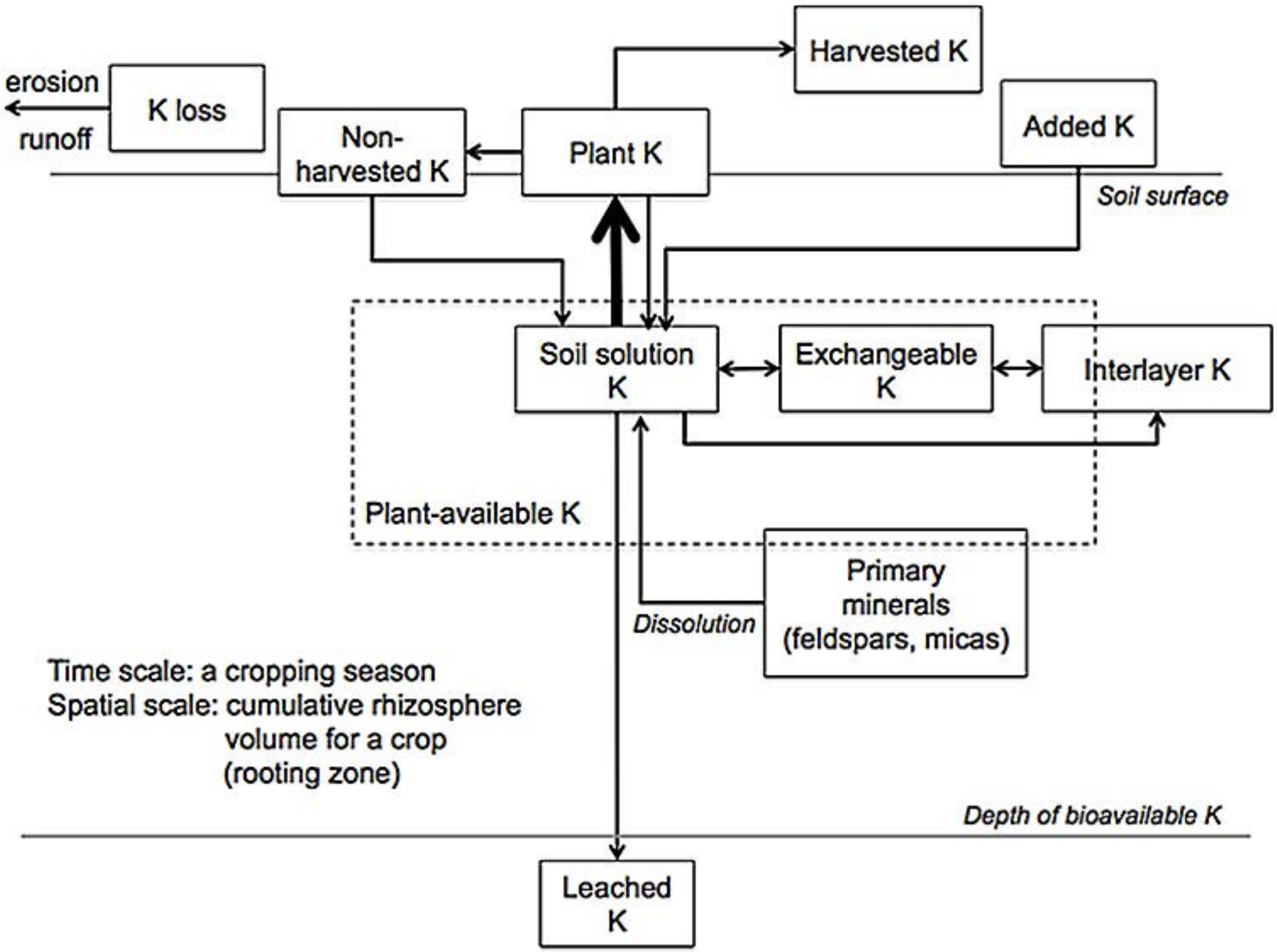
Our revised potassium cycle for crops and soils



LTEs used for

(1) Developing methods for soil testing and fertiliser recommendations;
(2) Assessing the effectiveness of different sources of applied K;
(3) Studying the fate of K Applied in fertilisers and manures and the K balance;
(4) Quantifying relationships between K pools, the importance of mineral reserves of K and the risk of depletion;
(5) Measuring critical K concentrations in crops;
(6) Showing the importance of balanced nutrition;
(7) Studying interactions between tillage and K distribution;
(8) Model development and testing.

1. Soil Testing and Fertiliser Recommendations

“LTEs…will provide the basic information needed to guide extension work … They will provide information on:

1. Basic data required for the calculation of nutrient cycles.

2. Information on responses to fertilizers and the interactions between nutrients and between nutrients and other inputs (such as irrigation and/or pesticides) to the system.

3. A basis for the associated work involving soil analysis and crop composition.”

1. Soil Testing and Fertiliser Recommendations

"All this information is required to derive the correct recommendations for the amounts of fertilizers to be used and the times when they should be applied ...

At present, there are too few of these experiments … and I would insist that they should have the highest priority as they are essential for the correct and efficient management of fertilizers."

(Cooke, 1985, *Proc. 19th Coll. Int. Potash Inst.*, Bern)

1. Soil Testing and Fertiliser Recommendations

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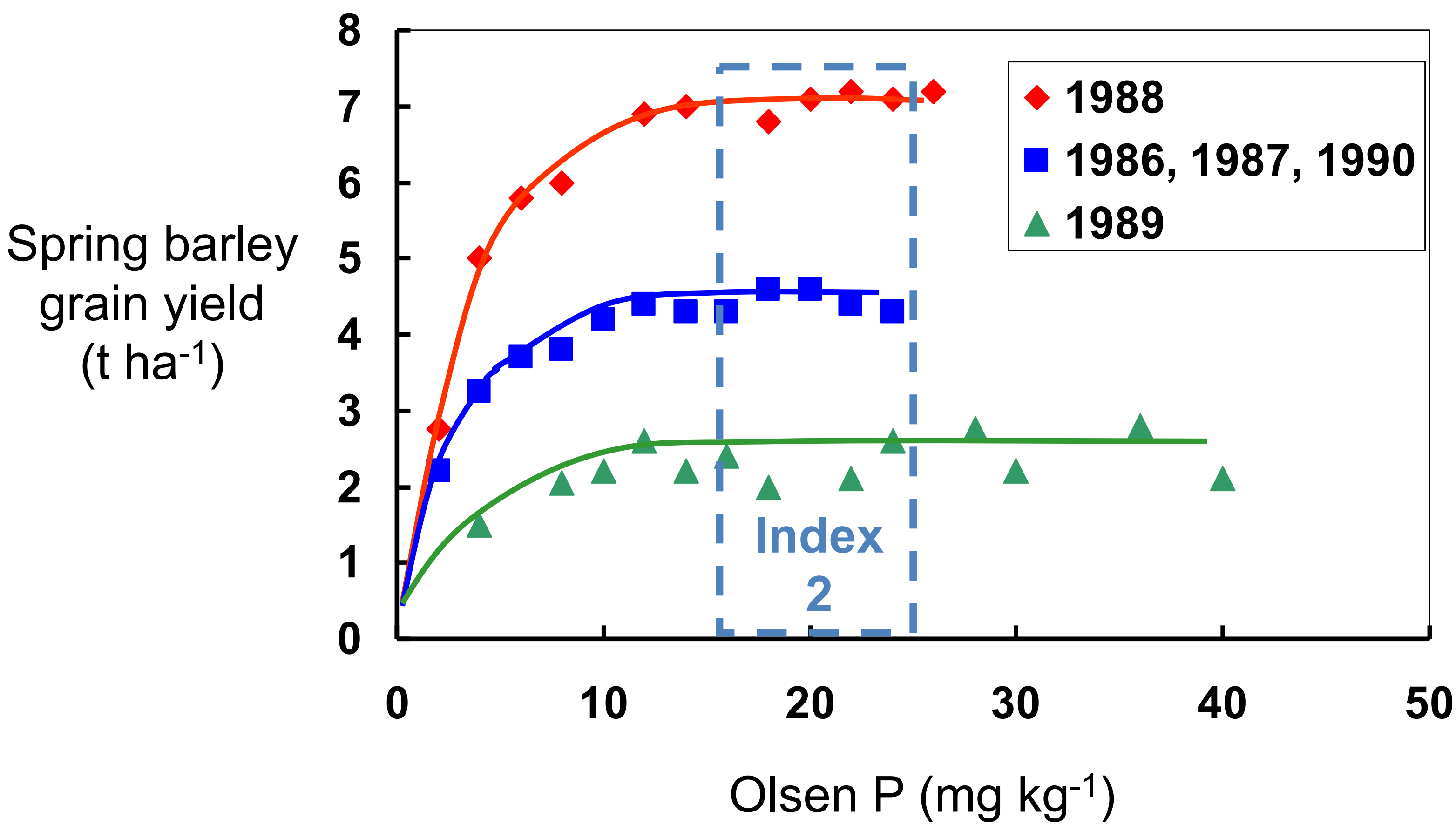
Based on the Index system and proven critical levels for soil P and K from many field experiments.



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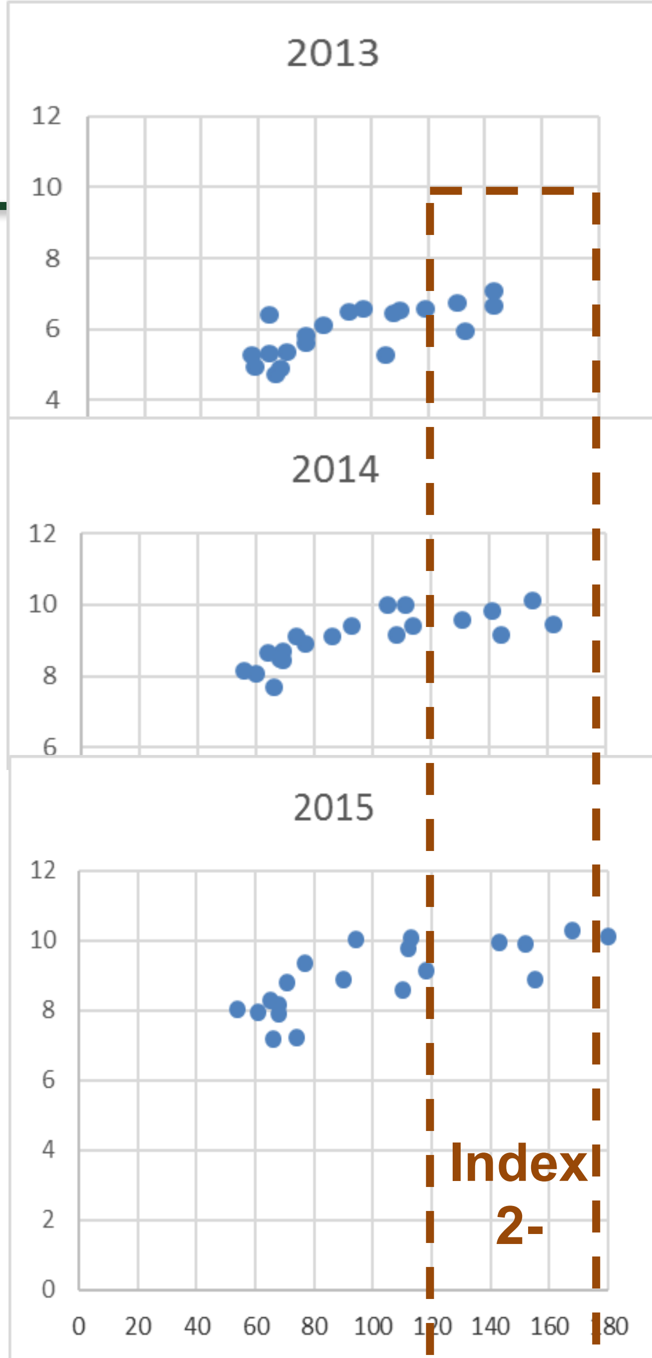
1. K recommendations

Wheat grain yield vs Kex,

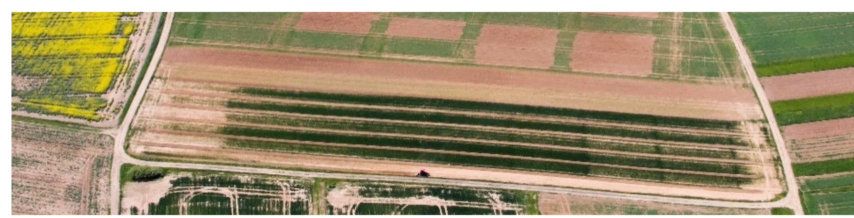
Exhaustion Land,

Rothamsted

Grain yield (t ha^{-1})



Kex (mg kg^{-1})



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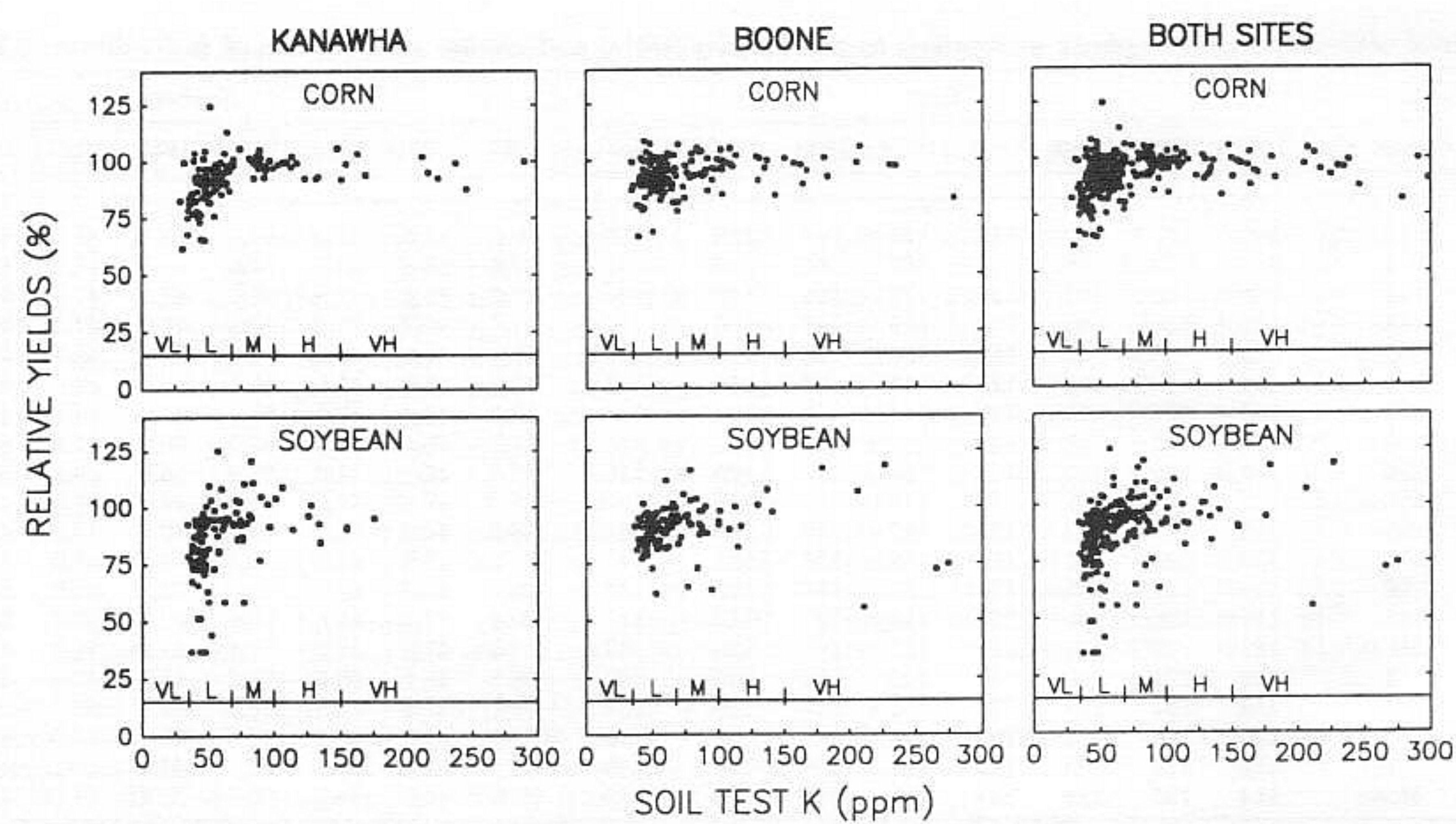
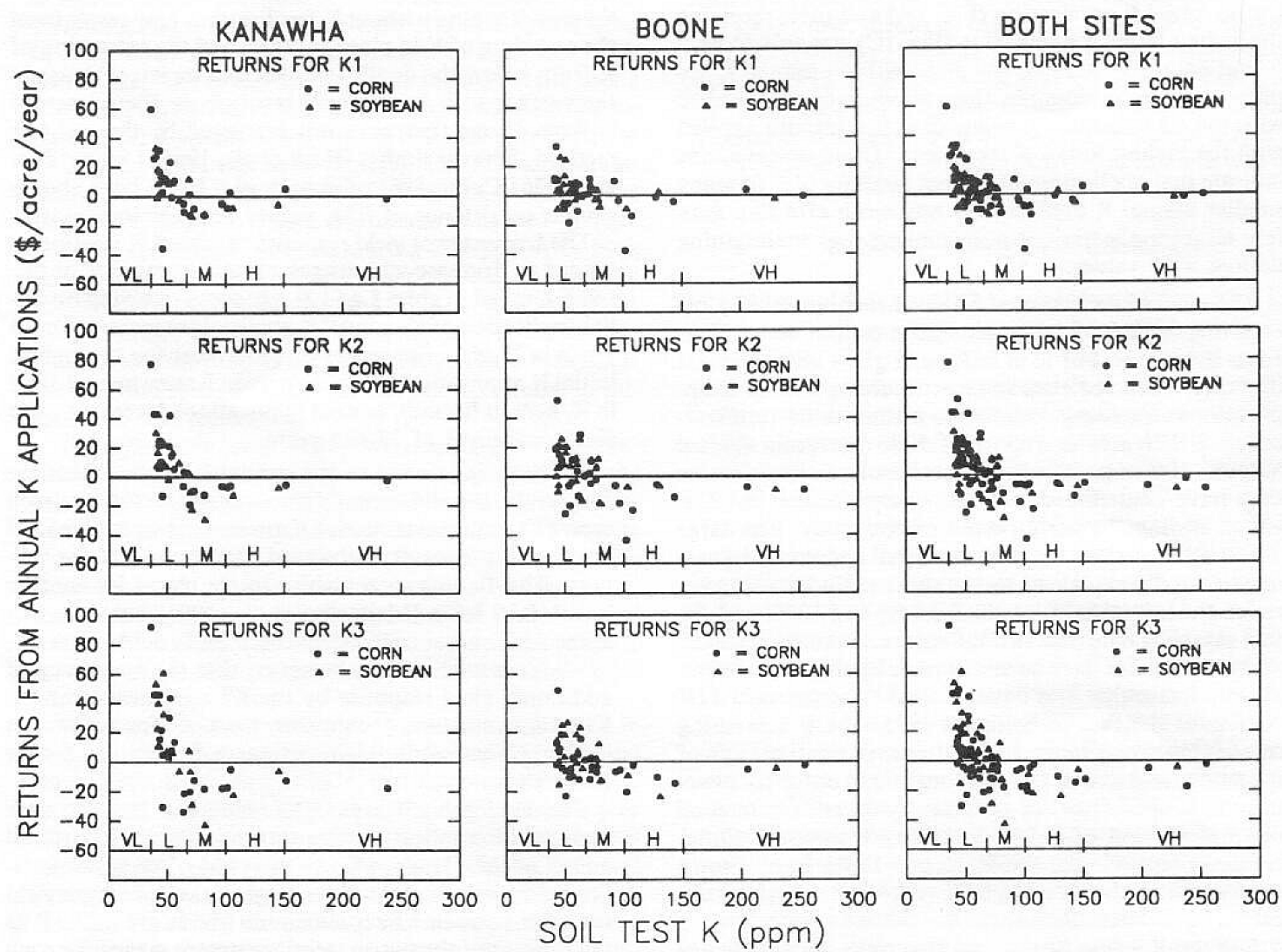
1. K recommendations: US field experiments



Mallarino *et al.*, 1991, *J. Prod Ag*. **4**, 560-566.

1. K recommendations: US field experiments

Economic returns



Mallarino *et al.*, 1991, *J. Prod Ag*. **4**, 560-566.

2. Effectiveness of Different Sources of Applied K

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- LTEs at Rothamsted, Bad Lauchstaedt and Skierniewice used to assesses the fate of K derived from fertilizers and organic manures.
- Plant availability and utilization of applied K partly related to clay content, more closely to mineral and organic cation exchange surfaces and, at Rothamsted, to K fixation capacity.
- The recovery of K from fertilisers was least in the most strongly K fixing soil (Rothamsted; 44% maximum utilisation); most in the soil with the highest CEC (Bad Lauchstaedt; 62% maximum utilisation).
- Recoveries of K from farmyard manure (FYM) varied from 22–117%.
- The effectiveness of mineral K fertilizer decreased when applied in combination with FYM because FYM was the preferred source of K.

  Why?

(Blake *et al.* 1999. *Plant & Soil* **216**, 1-14)

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2. Effectiveness of Different Sources of Applied K

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FYM preferred source of K (i.e. K more available) because:

- ? Underestimation of K in FYM, or K in FYM is more soluble.
  (Williams and Cooke, 1971, *Rothamsted Report for 1970*, Part 2, pp 68-97).
- ? K in the FYM plots is held on organic exchange sites that are not in equilibrium with non-exchangeable K on clay mineral exchange sites.
  (Addiscott and Johnston, 1975, *J. Agric. Sci., Camb*. **84**, 513-524).
- ? Well-degraded OM coats mineral surfaces and blocks K-selective sites
  (Goulding & Talibudeen, 1984, *J. Soil Sci*. **35**, 397-408).

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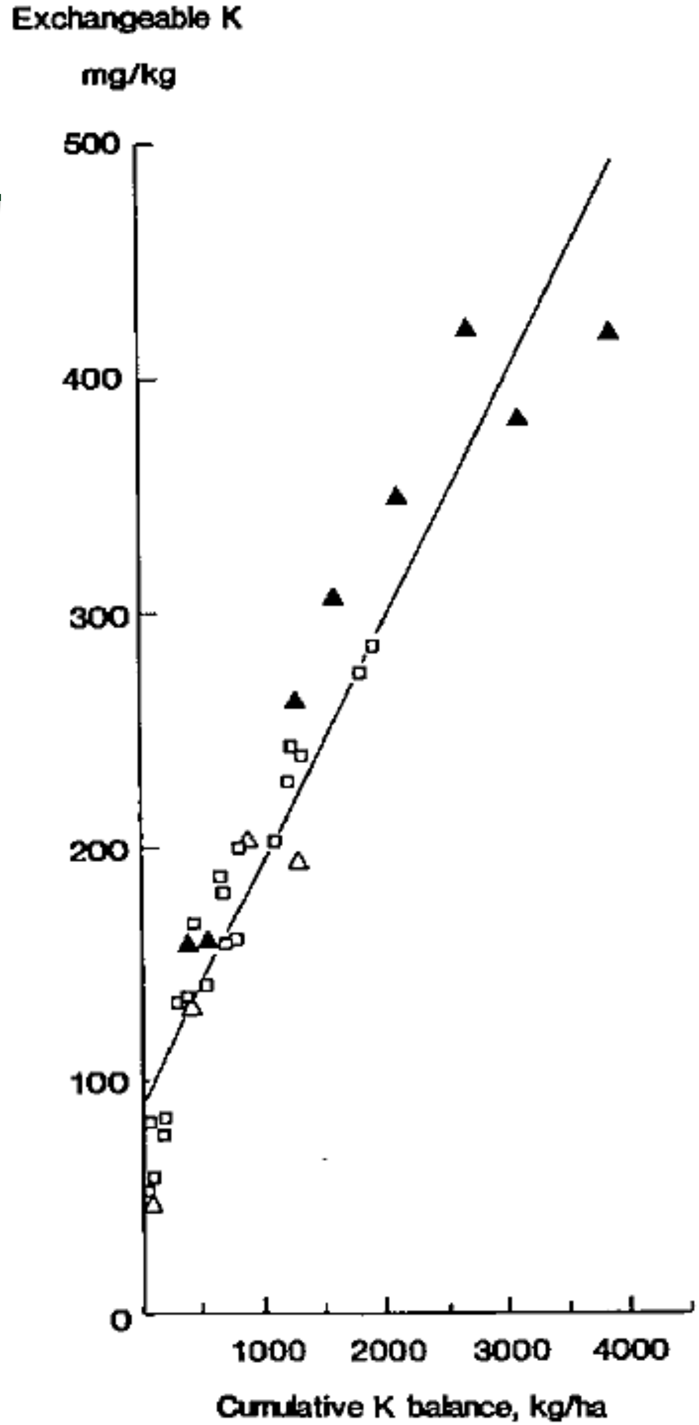


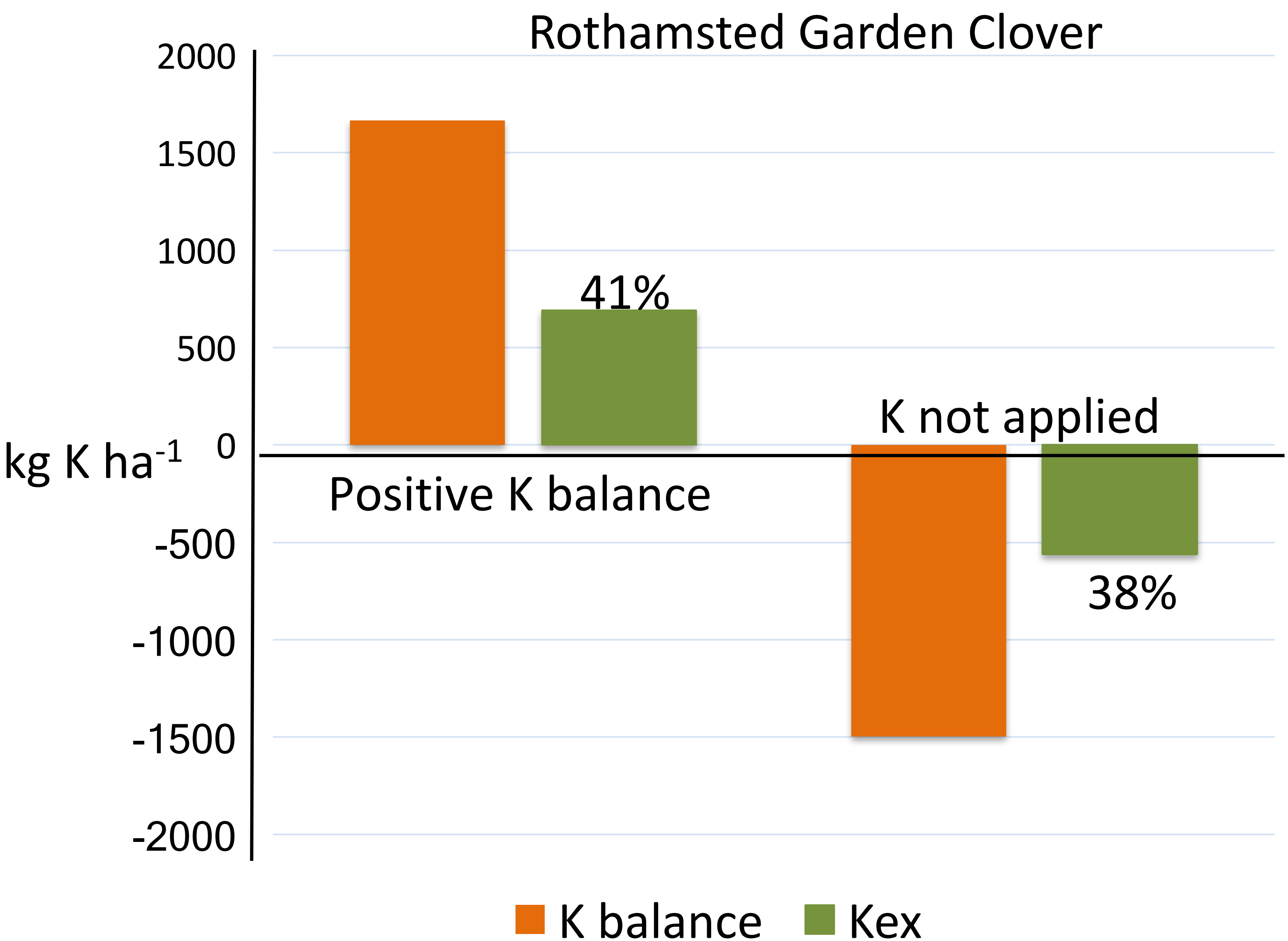
3. Fate of K Applied in fertilisers and manures and the K balance

20-year trial at Woburn Farm.

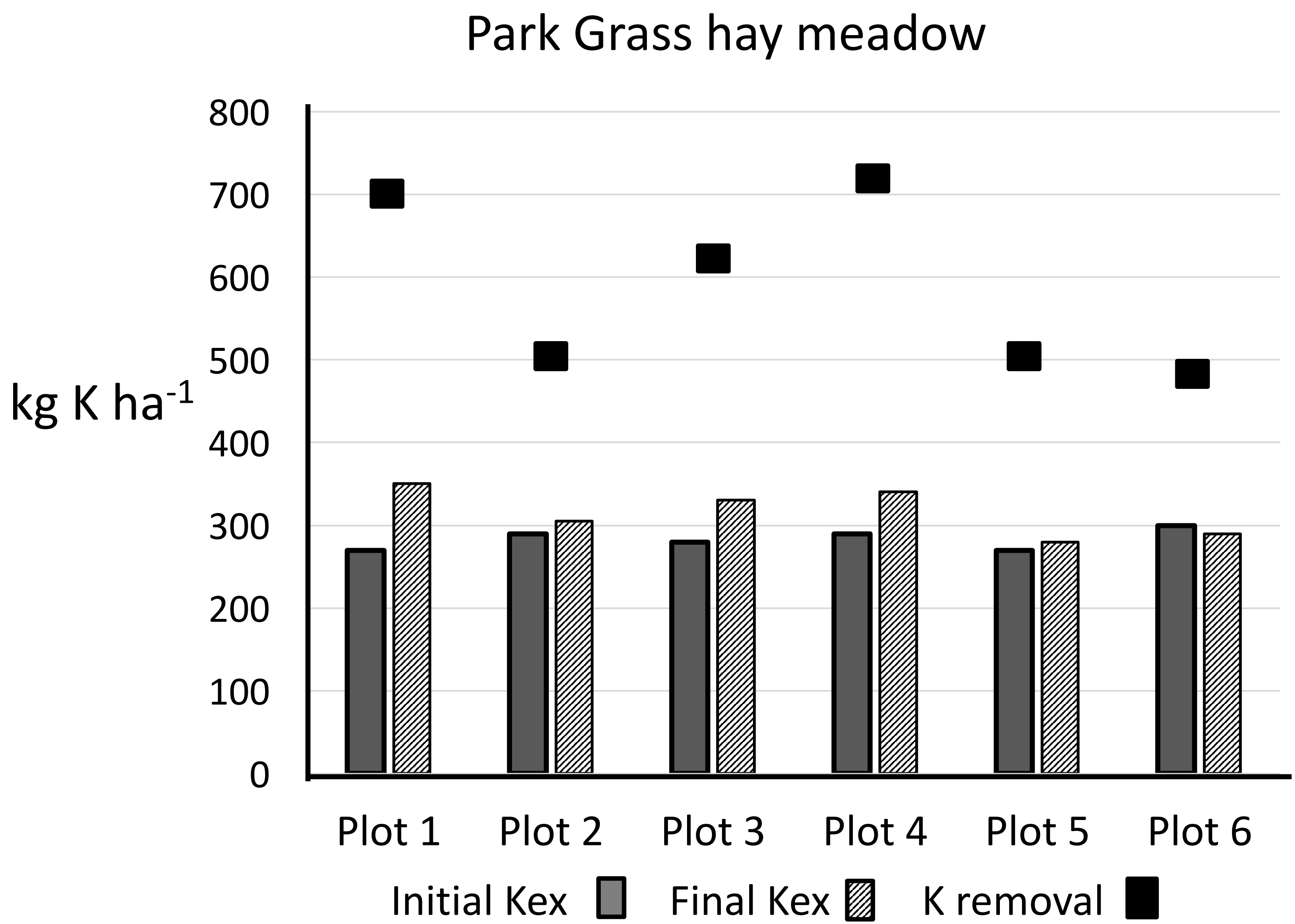
K as:

- □ Fertiliser
- △ FYM
- ▲ Fertiliser+FYM

3. Fate of K Applied in Fertilisers and Manures and the K Balance



3. Fate of K Applied in Fertilisers and Manures and the K Balance



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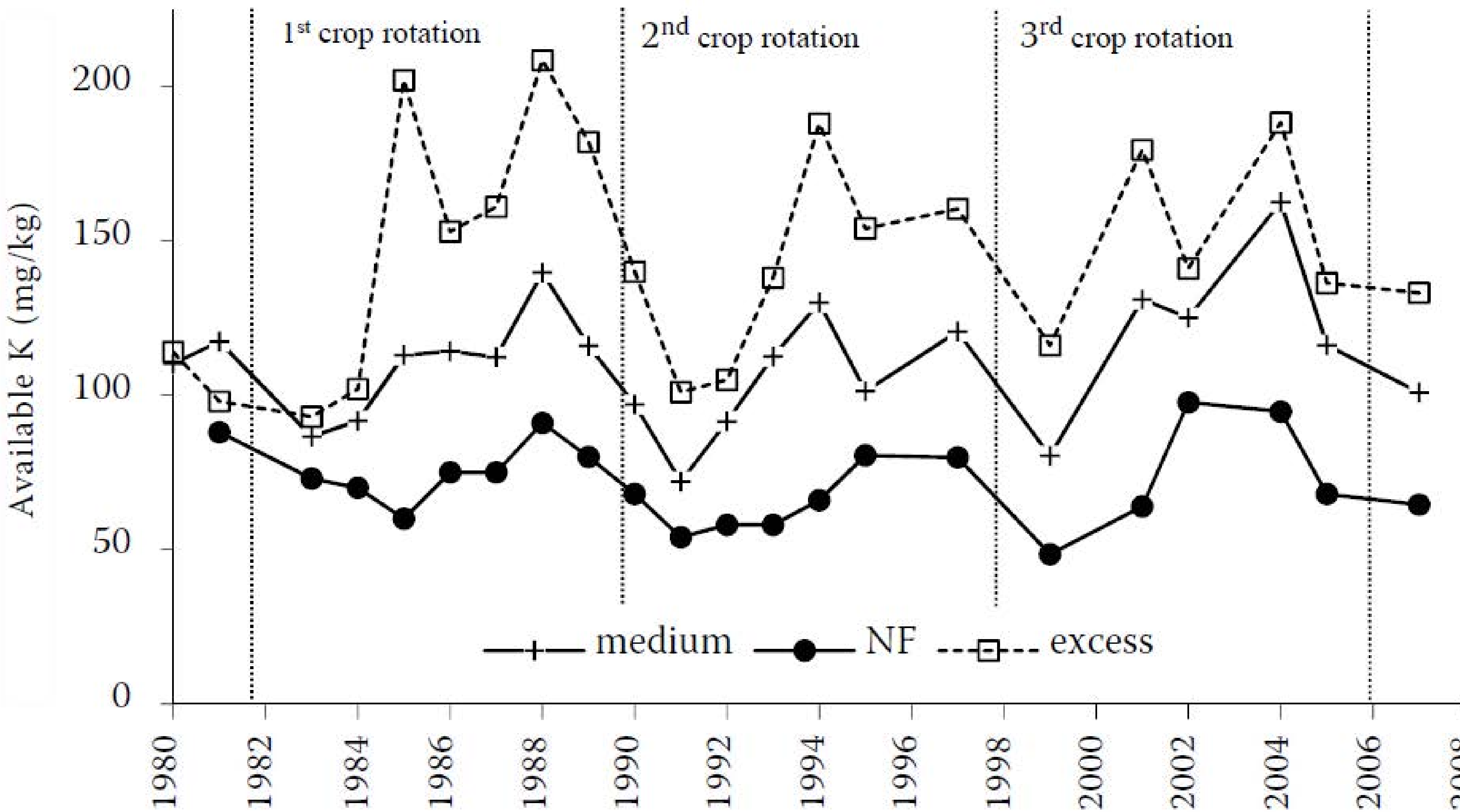
3. Fate of K Applied in Fertilisers and Manures and the K Balance

- Plant-available K dynamics measured in an 8-year crop rotation started in 1980.
- 10 combinations of KCl and FYM.
- Approximate K balance achieved with 153 kg K ha^{-1} yr^{-1}.
- Proportionally larger applications needed by the most demanding crops - silage maize and sugar beet.
- Changes in Kex mirrored the K balance.
- Kex was affected primarily by the crop and some unexplained factors.
- Interannual weather fluctuations and field differences had little effect.

(Madaras & Lipavsky, 2009, *Plant Soil Envir*. **55**, 334-343.)

3. Fate of K Applied in Fertilisers and Manures and the K Balance

ROTHAMSTED RESEARCH



(Madaras & Lipavsky, 2009, *Plant Soil Envir.* **55**, 334-343.)

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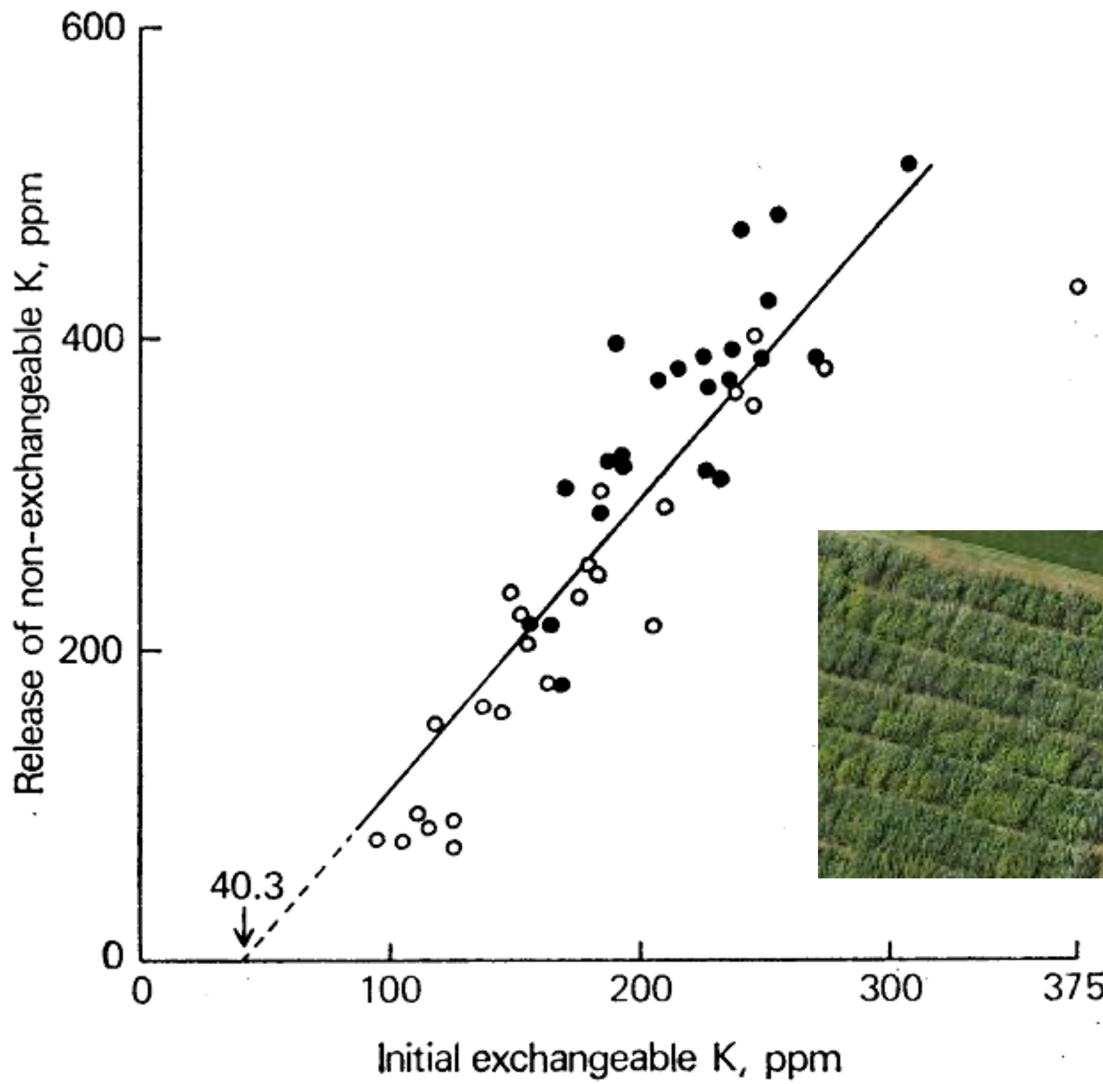
4. Relationships between K pools: release of Ki+Kl vs Kex

Agdell, sampled in 1967



4. Mineral reserves of K and the risk of depletion

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- 40-year old field trial with a range of K application rates, established at 8 sites of different climate and soils.
- K-feldspars dominant source of K when K balance was negative.
- In control treatments, the calculated average depletion of Kex was 18 kg ha^{-1} yr^{-1} and the average depletion of Ki was 12 kg ha^{-1} yr^{-1}.
- Ki accounted for 6–31% of the K budget.

(Madaras *et al.* 2014. *Plant Soil and Env.*, **60**, 358-363.)

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4. Mineral reserves of K and the risk of depletion

ROTHAMSTED RESEARCH

- 16-year old experiment in Brazil
- Assessed the contribution of non-exchangeable forms of K to crop removal.
- Estimated the recommended K fertiliser rate as the amount exported in the crop, i.e. used fertiliser to balance crop removals and maintain soil K.
- Calculated the average change in Ki (1.3 mg kg^{-1} soil) per 1 kg ha^{-1} yr^{-1} K balance.
- Applying insufficient K resulted in a significant depletion of Ki, greater than that of 'available K' (Ksl+Kex).

(Kaminsky *et al*. (2010) *Revista Brasileira De Ciencia Do Solo*, **34**, 783-791.

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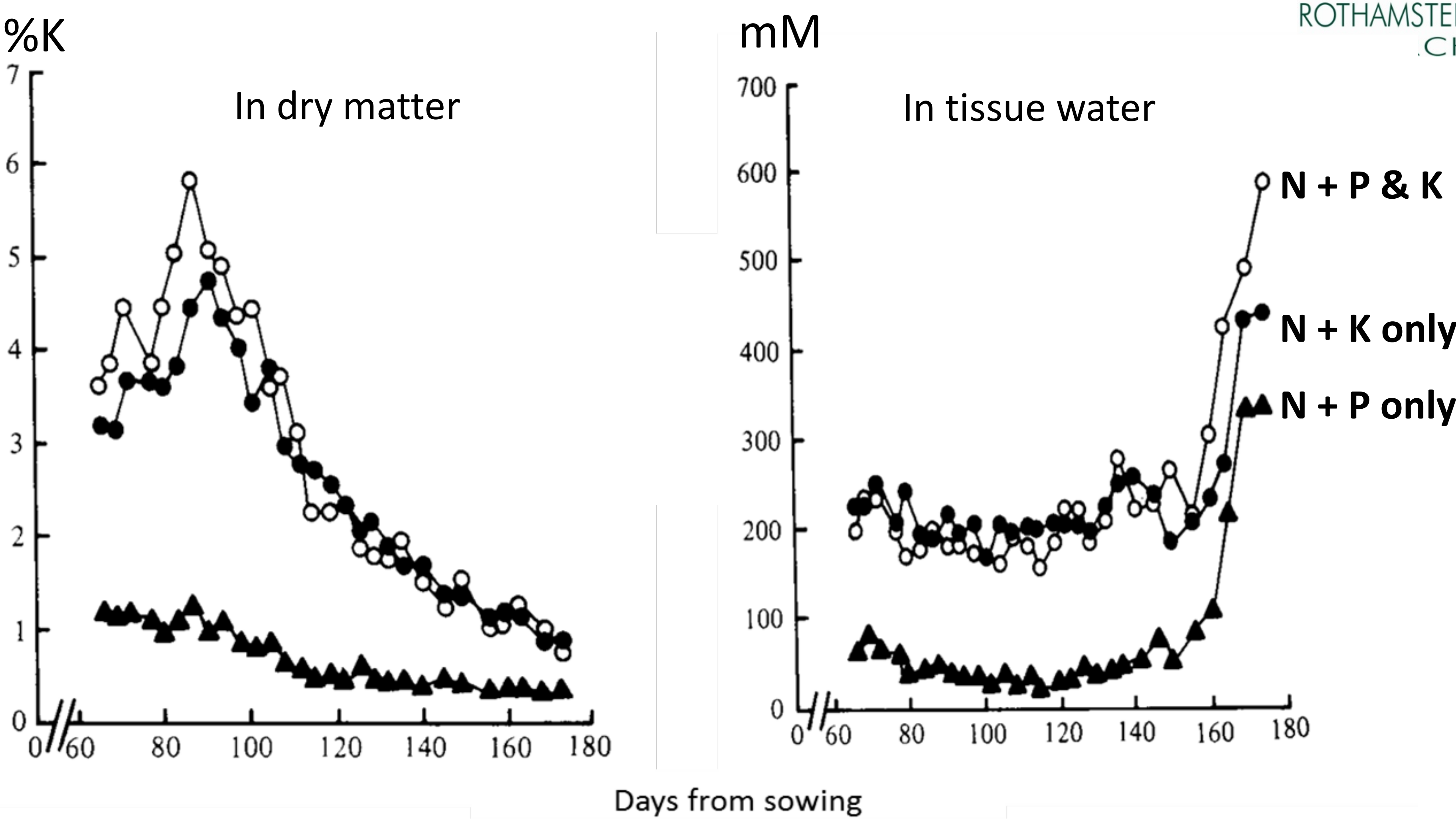
5. Critical K concentrations in crops



Exch. K 300 mg kg^{-1} O,●; Exch. K 50 mg kg^{-1} ▲

Leigh & Johnston 1983 *J. Agric. Sci*. **101**, 741-748.

5. Critical K concentrations in crops

- Kex = 325 mg kg^{-1}, tissue water K was approximately 200 mM
- Kex = 55 mg kg^{-1}, tissue water K was approximately 50 mM
- Yields of grain and straw less at the lower Kex and 50 mM tissue water
- Tissue water K could be used to identify soils with and without adequate levels of plant-available K.

Leigh & Johnston 1983. *J. Agric. Sci.*, **101**, 675-685 & 741-748.

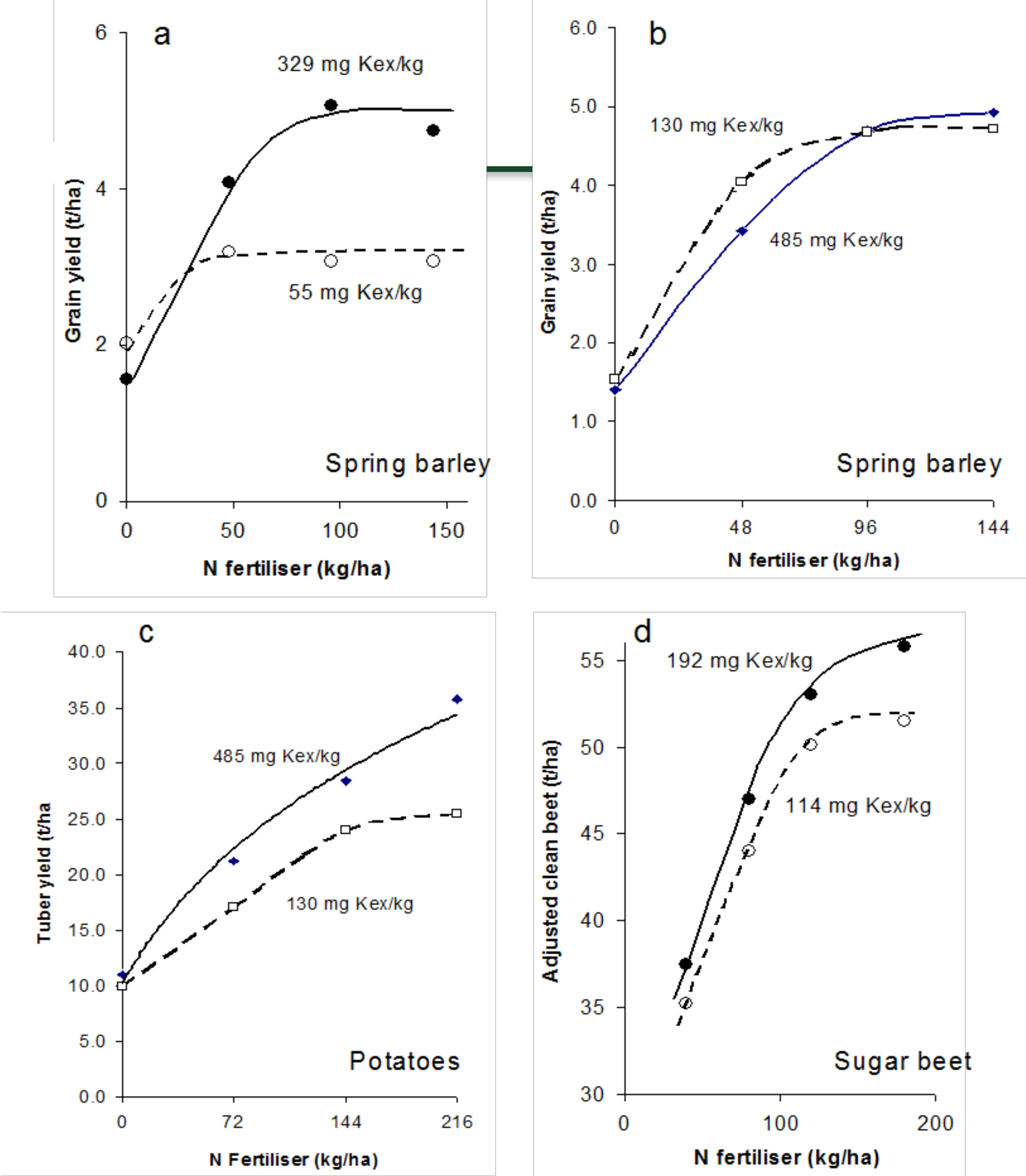
6. Balanced nutrition

- Globally, the ratio of N:P_2O_5:K_2O had changed from
  2.5 : 1.3 : 1 in the 1980s
  3.6 : 1.4 : 1 in 2002
  as N consumption outstripped that of K, despite many crops needing as much if not more K than N and proven strong interaction between K and N.
  (Magen, H. 2008. *Turkish J. Ag. Forestry*, **32**, 183-193)
  (Johnston, A.E. & Milford, G.F.J. 2012. Potash Development Association. 16 pp)

- Positive interaction between K and P for corn and soybeans in the US.
  (Mallarino, unpublished data)

6. Balanced nutrition

N x K interactions



Conclusions

- LTEs provide benchmark soils for calibrating methods of soil analysis.
- LTEs show that the effective recycling of organic manures is essential for maintaining and improving K supply and overall soil fertility.
- LTEs reveal the details of K exchange processes in the soil and show the importance of soil reserves and which soils release sufficient of these to supply crop needs.
- LTEs best reveal the K balance and show whether applications of K in fertilisers and manures are sufficient to avoid soil degradation.

Conclusions

- LTEs show the importance of balanced nutrition and key nutrient interactions such as those between N and K.
- LTEs show how tillage interacts with K supply and distribution in the soil.
- LTEs are invaluable for the development and calibration of K cycle models.

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Acknowledgements

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- IPNI/IPI for inviting me and funding my attendance.
- Co-authors for help in preparing the chapter and presentation.
- Scott Murrell and Phyllis Pates for help and support.

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Long-Term Experiments

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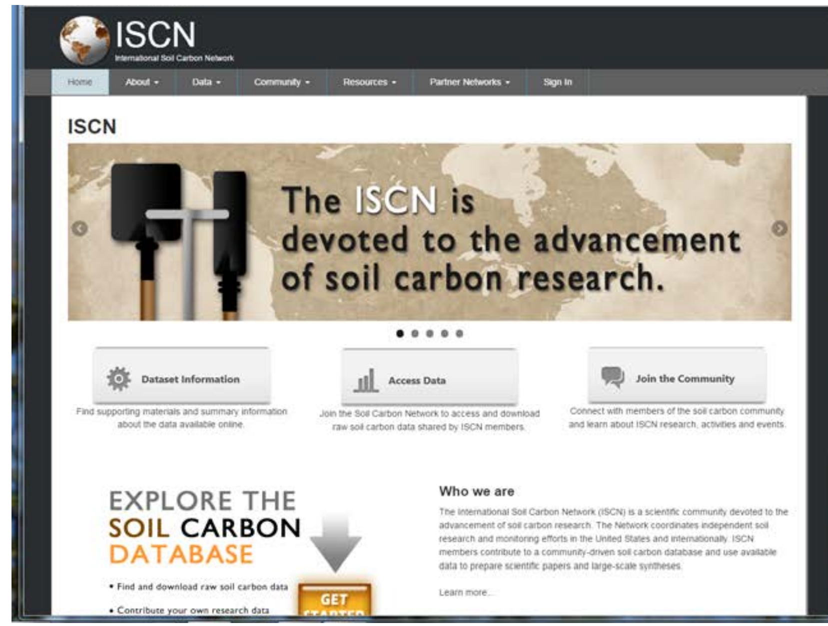
International Soil Carbon Network (ISCN) includes >250 LTEs
http://iscn.fluxdata.org/partner-networks/long-term-soil-experiments/

Long-Term Ecological Research Network
https://lternet.edu/



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3. Fate of K Applied in Fertilisers and Manures and the K Balance

- Garden Clover Experiment: total positive balance of 1667 kg K ha^{-1} over a period of 10 years increased the content of Kex by only 690 kg ha^{-1} (41% of the K balance)
- 59% of the K balance had gone into Ki, assuming that no K was leached.
- Subsequent long-term omission of K, and a negative K balance of 1494 kg K ha^{-1} due to crop removal, resulted in a reduction in Kex of only 563 kg K ha^{-1} (38% of the K balance).
- The other 62% of the K removed would have been supplied by Ki and Kl.

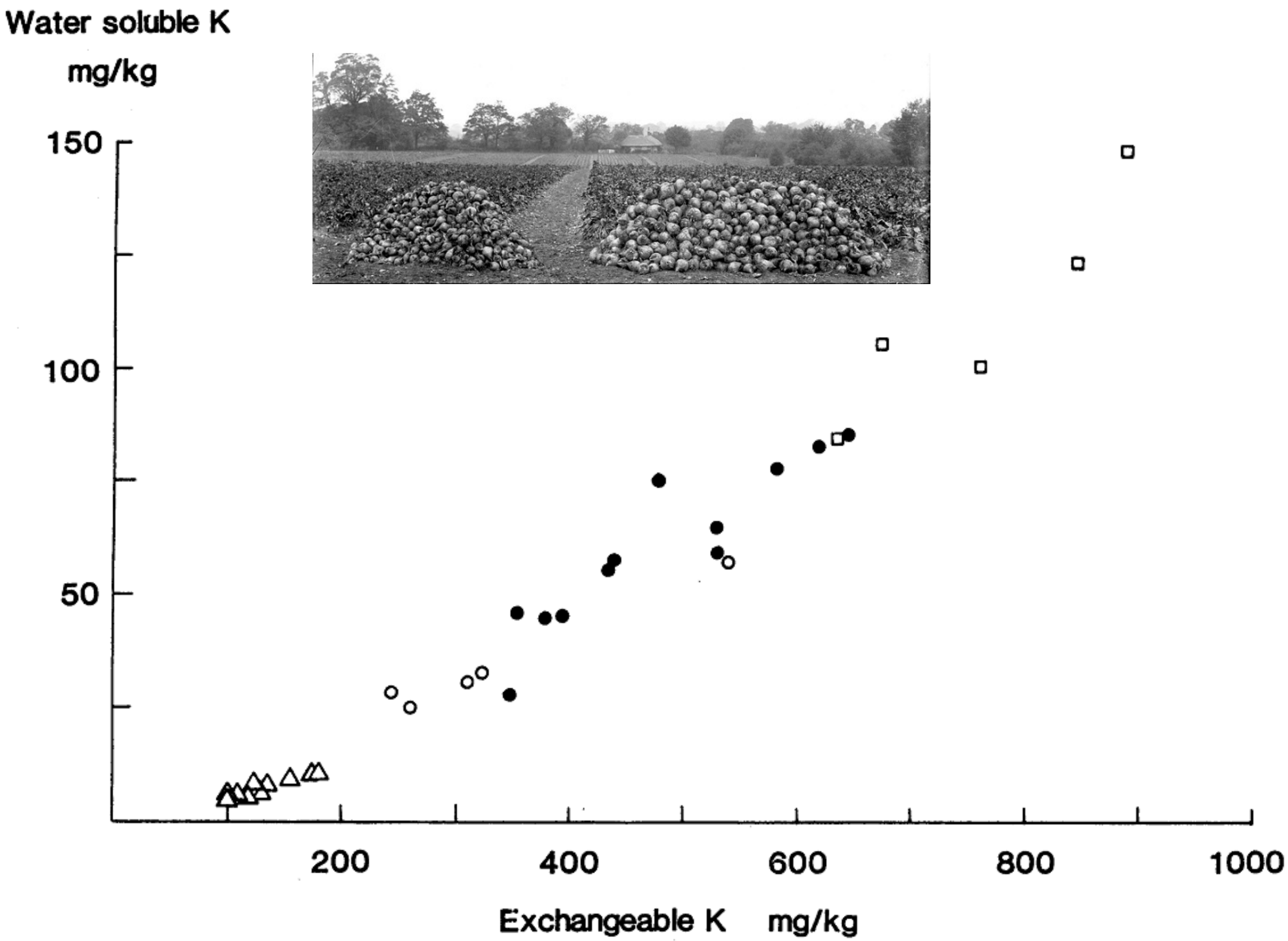
3. Fate of K Applied in Fertilisers and Manures and the K Balance

- K uptake, K use efficiency, and K balance in measured in 6 fertilizer treatments of long-term fertility experiments with rice at 11 sites in five Asian countries.
- Significant depletion of soil K reserves at almost all sites.
- Recommendations for K in most intensive irrigated rice systems insufficient to replace K removals.
- Efficient K management for rice should be based on the K balance, the achievable yield target, and the effective K-supplying power of the soil.

(Dobermann *et al*. (1996) *Nutrient Cyc. Agroecosys*. **46**, 1-10.)

4. Relationships between K pools: Ksl vs Kex

Barnfield, Rothamsted, sampled in 1958



Relationship between water soluble and exchangeable K in 1958, in the 0-23 cm depth of soils given K as: fertiliser, •; farmyard manure, o; fertilisers plus farmyard manure, ▲; or no K, Δ; since 1856

1. K recommendations: UK field experiments

Fig 6: Response of winter wheat & spring barley to soil K

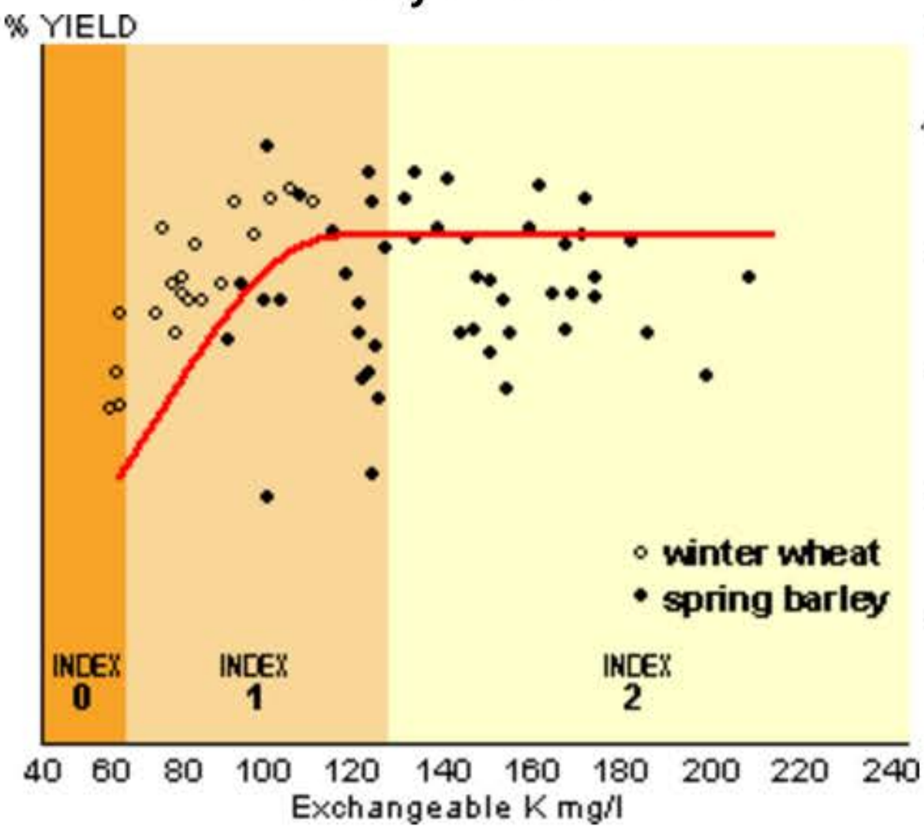
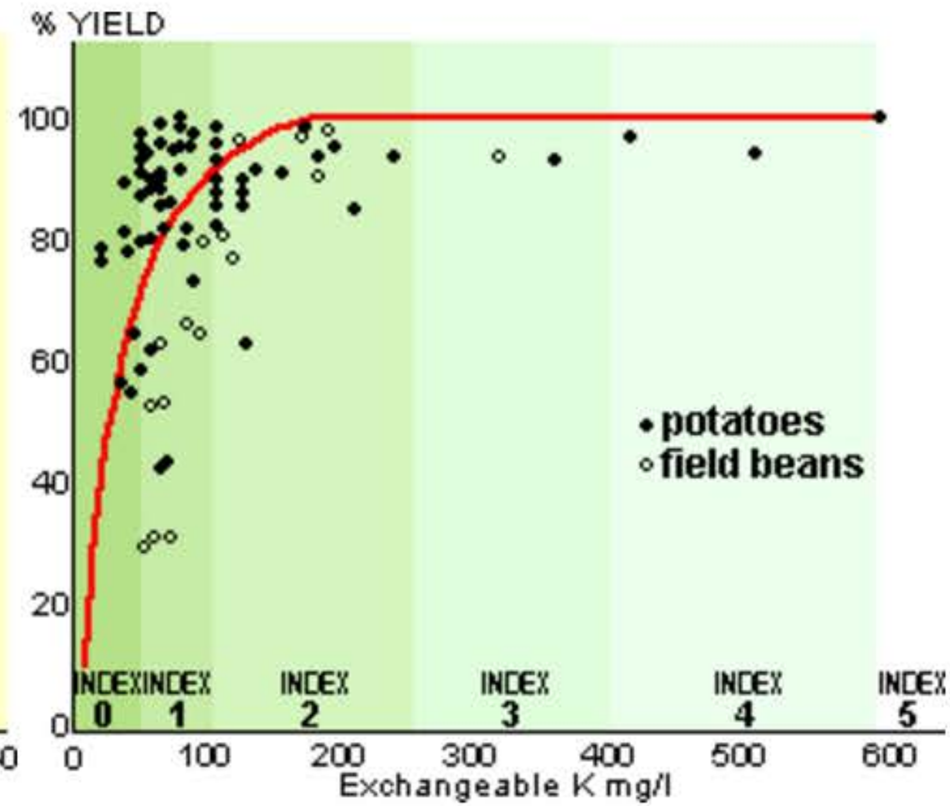


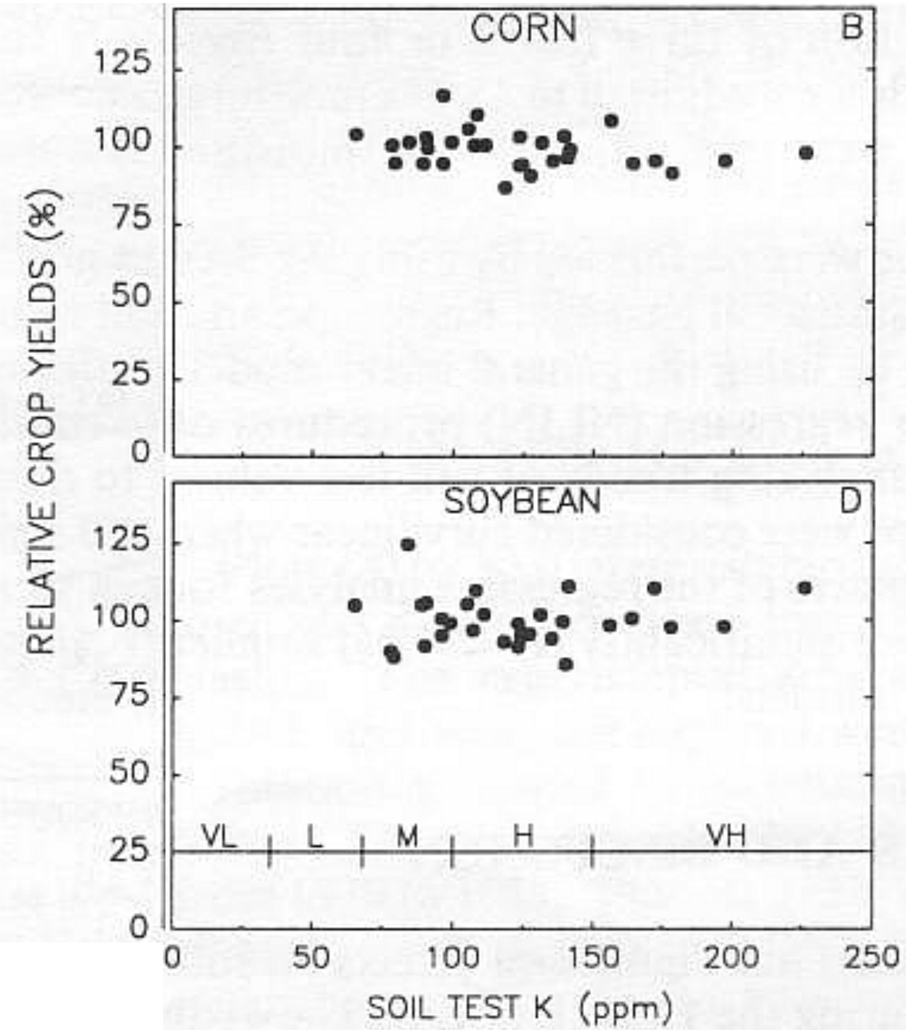
Fig 7: Response of potatoes & field beans to soil K

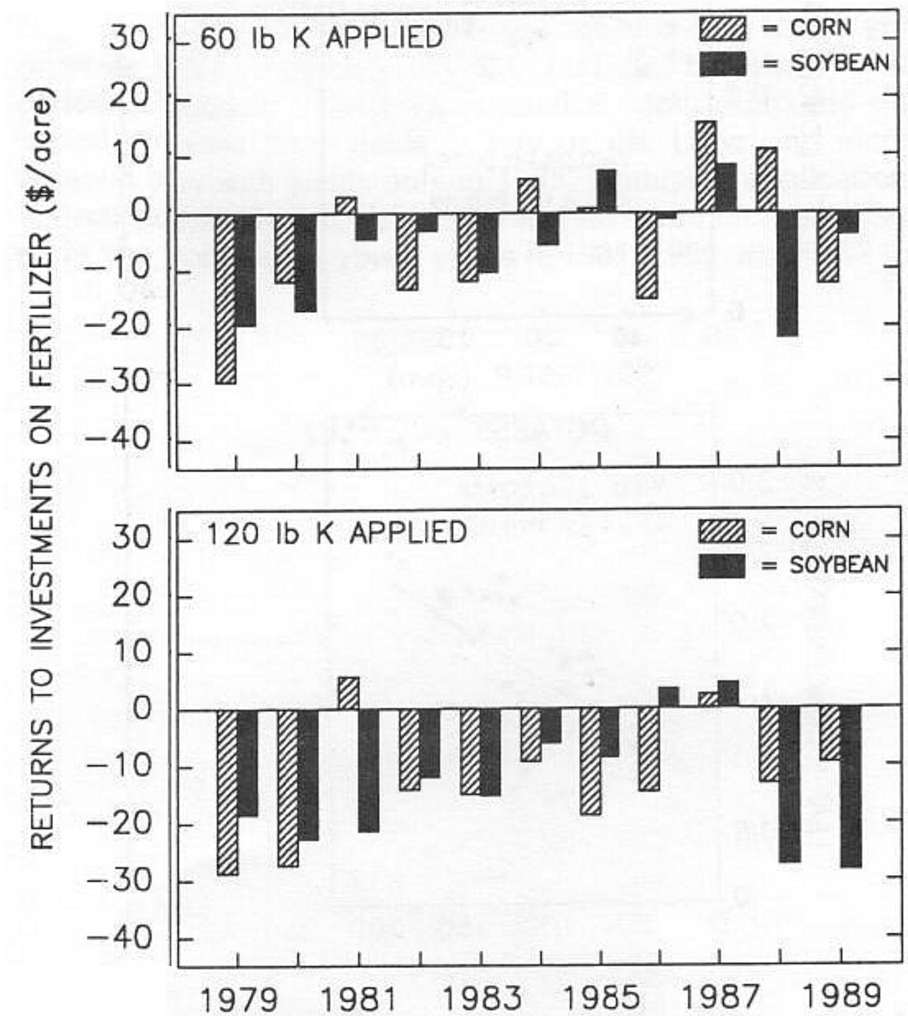


Potash Development Association, 2006, Leaflet 8, 'Principles of potash use'.

1. K recommendations: US field experiments

Economic returns





Mallarino *et al.*, 1991, *J. Prod Ag*. **4**, 312-317.

Effectiveness of Different Sources of Applied K

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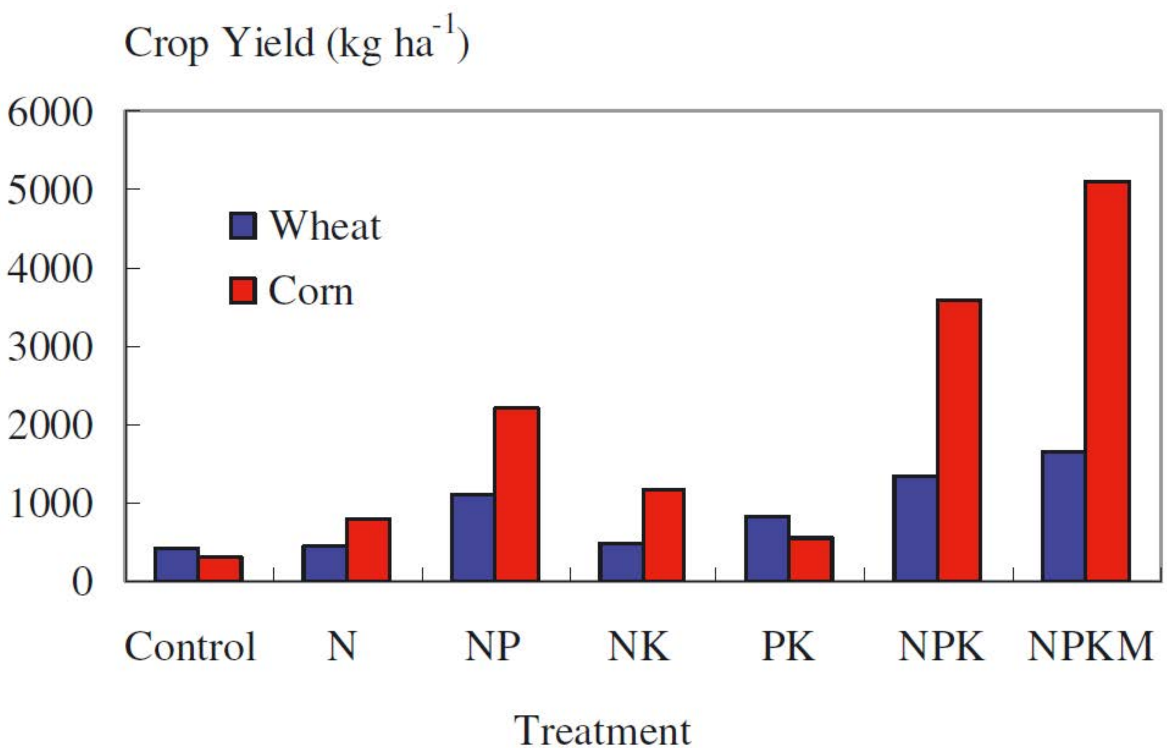
Well-managed combinations of chemical and organic fertilizers can sustainably achieve higher crop yields, improve soil fertility, alleviate soil acidification and increase nutrient-use efficiency compared with only using chemical fertilizers.



(Miao *et al*. 2011. *Agron. for Sust. Dev*., **31**, 397-414.)

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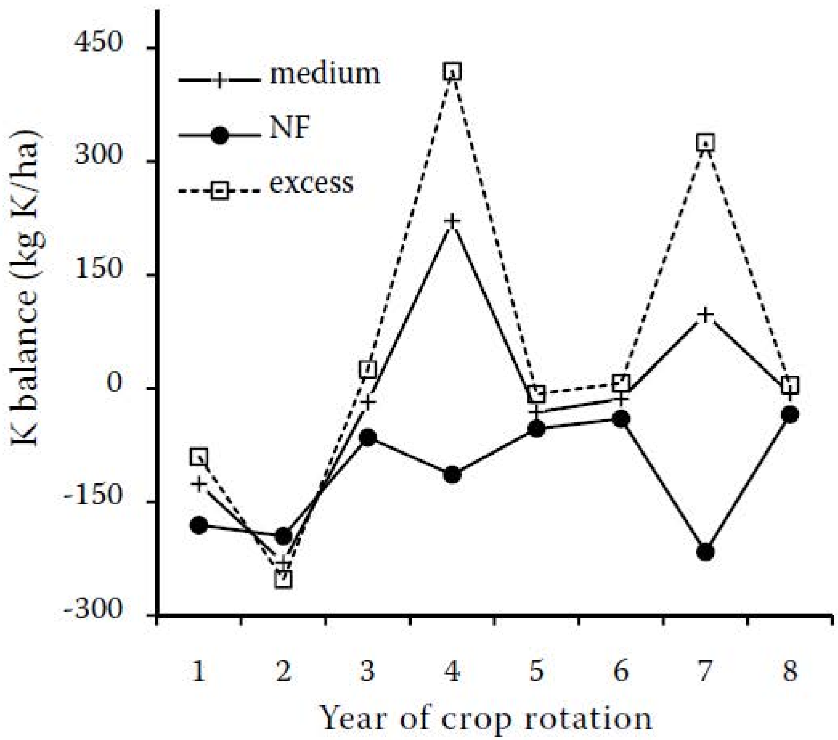
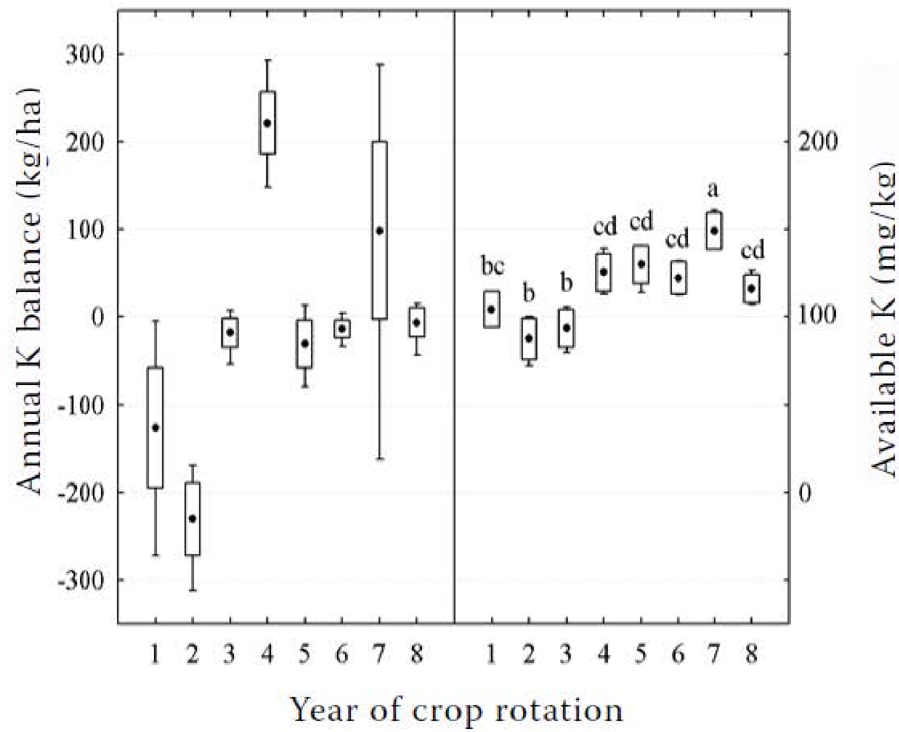
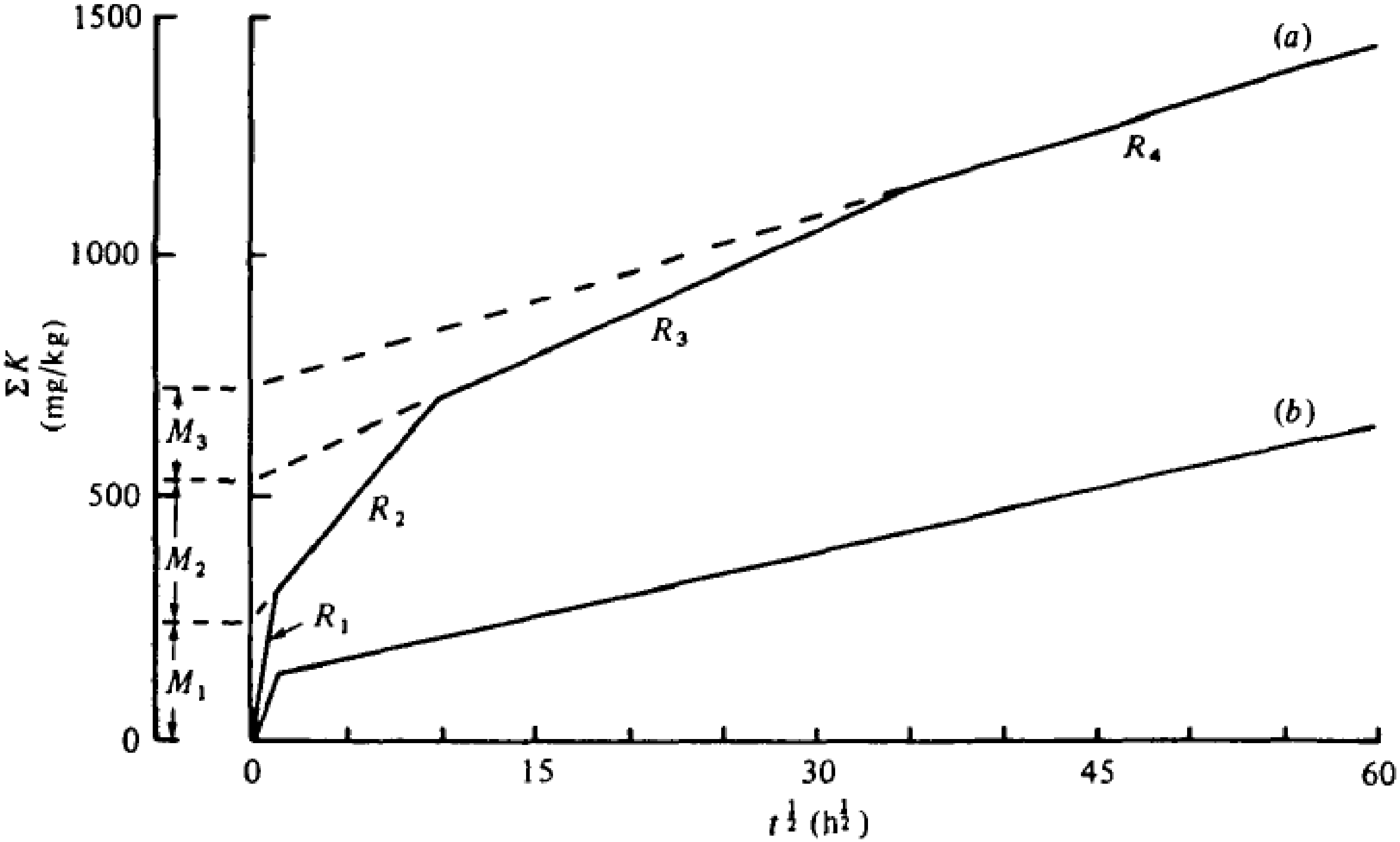
Fate of K Applied in Fertilisers and Manures and the K Balance





(Madaras & Lipavsky, 2009, Plant Soil Envir., 55, 334-343.)

Soil Testing and Fertiliser Recommendations



K released to Ca-resin by (a) the Denchworth series soil containing 49% clay and (b) a soil from Germany containing 2% clay.